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# Assessment of Irrigation Return Flow Models

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# ASSESSMENT OF IRRIGATION RETURN FLOW MODELS

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## ABSTRACT

Throughout the Western United States irrigation return flows contribute to the problem of water quality degradation. Evaluating the effectiveness of alternative management strategies involves models which simulate the processes encompassed by irrigated agriculture. The development and application of these models require multidisciplinary expertise. A workshop involving fifteen specialists in the varied aspects of irrigation return flow modeling was held to review the status of these models. Irrigation return flow and conjunctive use models recently developed by the Bureau of Reclamation served as focal points for the workshop. As the field verification and potential applications of these models were discussed, several general problems were identified where further investigation is needed. Particular emphasis was given to the description of the spatially varied aspects of soil, crop, and aquifer systems, and the proper alignment of model objectives with available data. The large number and diversity of existing models illustrate the individualistic nature of irrigation return flow modeling. In order to affect more widespread utilization of existing models, a systematic procedure should be developed to update and disseminate this modeling technology.

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The author is indebted to the individuals who helped with the local arrangements during the workshop. Ms. Lee Kettering and Mr. Stephen W. Smith assisted in arranging for participant travel and local activities.

Finally, the writer wishes to recognize the efforts and advice given by the Project Officer, Dr. Arthur G. Hornsby, whose willingness to act as co-host at the workshop facilitated fulfilling the objectives of this project.

# SECTION I

# CONCLUSIONS

Irrigation return flows may contain significant concentrations of salinity, nutrients, insecticide and herbicide residues, and sediments which affect the beneficial uses of receiving waters. Management techniques are being developed and implemented to control and reduce water quality degradation to a much smaller level while maintaining favorable conditions for crop production. This requires a detailed understanding and evaluation of the numerous processes that affect return flow. The irrigation return flow model is a vehicle for combining, in one simulation program, what is known about these processes for the purpose of evaluating alternative plans for their control.

Most modeling efforts have tended to express the individual modeler's perception of the problem and its solution in limiting the scope of the model application. The resultant models, while individualistic in nature, are generally composed of a multi-level structure in which various processes are combined and integrated to simulate the system. They vary from simplistic to highly refined treatments of hydrologic and water quality related processes and conditions. The structural level employed depends on the scope and objectives of the study being conducted and the experience of the modeler. In addition to the individualistic model structures are the often unique irrigation return flow situations. A majority of workshop responses favored using submodels of limited scope which consider individual processes within the irrigated environment. The flexibility for assembling submodels into the desired operational format indicated by a specific problem is thus possible. The need for careful documentation and field verification was considered a prerequisite to testing the capability of a model whatever its structure and scope.

Of the various segments of an irrigation return flow system, modeling improvements are needed in the simulation of root zone moisture and nutrient extraction, and groundwater flow and chemistry. The effects of the design and management of an irrigation system on subsurface moisture, salt, and nutrient movement were also regarded as a significant research area requiring additional investigation. Some segments of the return flow system such as evapotranspiration (except under trickle irrigation), soil chemistry,

drainage, and surface hydrology of irrigated areas were thought to be comparatively well defined and adequate at the present time for most modeling purposes.

The USBR models were introduced at the workshop for assessment by the participants. The conjunctive use model for river basins designed to simulate the basic irrigation return flow system and to predict its regional impact was considered a useful tool for such applications as: (1) indicating the impact of an irrigated area on the region's water resources; (2) producing regional water quality planning and management information; and (3) assessing the environmental impact of a proposed development or change.

The USBR models for detailed simulation of irrigation return flow systems were generally well received. Recognizing that these models were among the most comprehensive and user oriented available, the group concluded that further improvements could be made in the areas of dynamic root water-nutrient extraction, two-dimensional soil moisture and salinity flow, nitrogen chemistry, and evaporation at the soil surface. Most of the participants indicated a desire to know more about the detailed models and the opportunity to use them in their own research programs.

In most model applications to large systems, one of the major problems is the spatially varied nature of field and soil conditions. Soils for example may exhibit vastly different characteristics from one locale to another in the same irrigated area. Consequently, individuals who expect to apply existing modeling technology should use extreme care in determining the representative nature of the data used as their input. Many parameters and data are not normally distributed, and thus, the arithmatic mean may not be a good estimation of central tendency. Increased knowledge concerning parameter distributions in the field should allow selection of more representative model input data.

Another problem is that most detailed models are formulated for small scale analyses where relatively large quantities of data are available and where much is known about the system being modeled. In scaling such models to large land areas, the comparative lack of detailed data may require the modeler to make assumptions which reduce the modeling reliability. In addition, if in expanding the model the sensitivity to certain assumptions is not sufficiently understood, a great deal of misapplication may result.

The workshop format effectively addressed each of the objectives set forth by this project. The short time allotted to each segment limited participant evaluation of some important modeling problems. Most of the participants, however, indicated it was time well-spent and believed their own modeling capabilities were improved by gaining a perspective as to how the work of other disciplines interfaced with their own. One conclusion indicated by most individuals present was a need for increased interaction between the different science disciplines (i.e., soil scientists, hydrologists, etc.).

## SECTION II

## RECOMMENDATIONS

This study indicates that an important need in the field of irrigation return flow modeling is the standardization of modeling technology. This will provide more widespread use of existing models, better interdisciplinary coordination, and less duplication. Work should be undertaken to identify and describe existing models relating to the varied aspects of irrigation return flow systems. Then a central program library comprised of these models could be developed where the models as well as their documentation and verification could be maintained. The library would be a central point for the dissemination of these models to the research and consulting communities when needed. A group of interdisciplinary specialists should be formed to evaluate each model submitted, test them on various computer systems, and then develop a structure for classifying and updating. In this way, the library may serve as a useful coordinating tool for research workers as well as those interested more specifically in planning.

A problem of improperly applying models no matter how well documented will always exist. However, a report or text written to describe the complex irrigation return flow system and how it may be simulated would help to minimize improper applications. It is probably necessary to develop this documentation at two levels. One level should be structured with the planner or administrator in mind where as the second would be written for use by the technical analyst. An information source such as these suggested documents should also be developed in coordination with a well experienced and interdisciplinary group of advisory personnel.

In the interim, the workshop concept is an effective mechanism for increasing the utilization and understanding of models already developed. Federal and state agencies performing modeling development work should use the workshop format to disperse their results to the various interested individuals. The workshop is also an efficient vehicle for acquainting administrators with the details of work being accomplished under their direction. In addition, training workshops would aid administrators in formulating specifications for research, implementation, and enforcement. The USBR models should be further exposed to a large group of

potential users outside of the Bureau who will be involved in future research and implementation activities as irrigation return flow quality control begins on a large scale. Publication of the results of the detailed USBR model results in the technical and scientific literature is strongly encouraged.

Several areas of needed research were identified. A procedure for describing the spatial variability of soil, crop, and groundwater properties should be developed. The sensitivity of models to their input data and assumptions requires consideration in light of the variability of systems under field conditions. Groundwater and aquifer data are comparatively unavailable, and therefore, should be emphasized in future data collection efforts. If irrigation practices involving low-tension, high-frequency water applications find widespread utilization, such as drip irrigation, additional work should be performed to determine the evapotranspiration rates under these conditions. The effects of an irrigation system design and operating practices should also be evaluated, especially for low-tension, high-frequency irrigation regimes.

# SECTION III

# INTRODUCTION

## STATEMENT OF PROBLEM

The application of water to agricultural lands where natural precipitation is inadequate for crop needs has provided the United States and other countries in the world with a more stable supply of food and fiber. Before the widespread concern for environmental quality it was generally accepted that the resulting increases in salinity, insecticides, herbicides, sediment and other pollutant loads in river systems were inevitable consequences. But under present social pressures, water quality degradation and control are receiving more attention. The capability for evaluating management alternatives on irrigation return flows was heretofore limited by the lack of suitable predictive models based on physical aspects of the many processes involved. These tools, which are commonly called models, are being developed so that it is presently possible to handle many of the complex processes related to irrigation return flow.

A simulation model is generally a set of mathematical relations applied to appropriate boundary conditions that attempts to simulate the relationships between variables in the natural system. It is used to understand the natural system and evaluate its behavior under proposed management alternatives. Researchers have been prolific in applying modeling concepts to the various segments of the hydrology in an irrigated area (Figure 1). To date, irrigation return flow models of all types are somewhat individual in nature because each model expresses the modeler's perception of his own particular solution to a problem. Most models are so unique that many active modelers find it is easier and more reliable to program for individual purposes that sift through the language barrier of another's program. Consequently, application of modeling advances is extremely slow and duplication or repetition is common.

One of the most exhaustive modeling efforts in the field of irrigation hydrology was recently undertaken by the Bureau of Reclamation, U.S. Dept. of Interior, with funding support and program direction from the U.S. Environmental

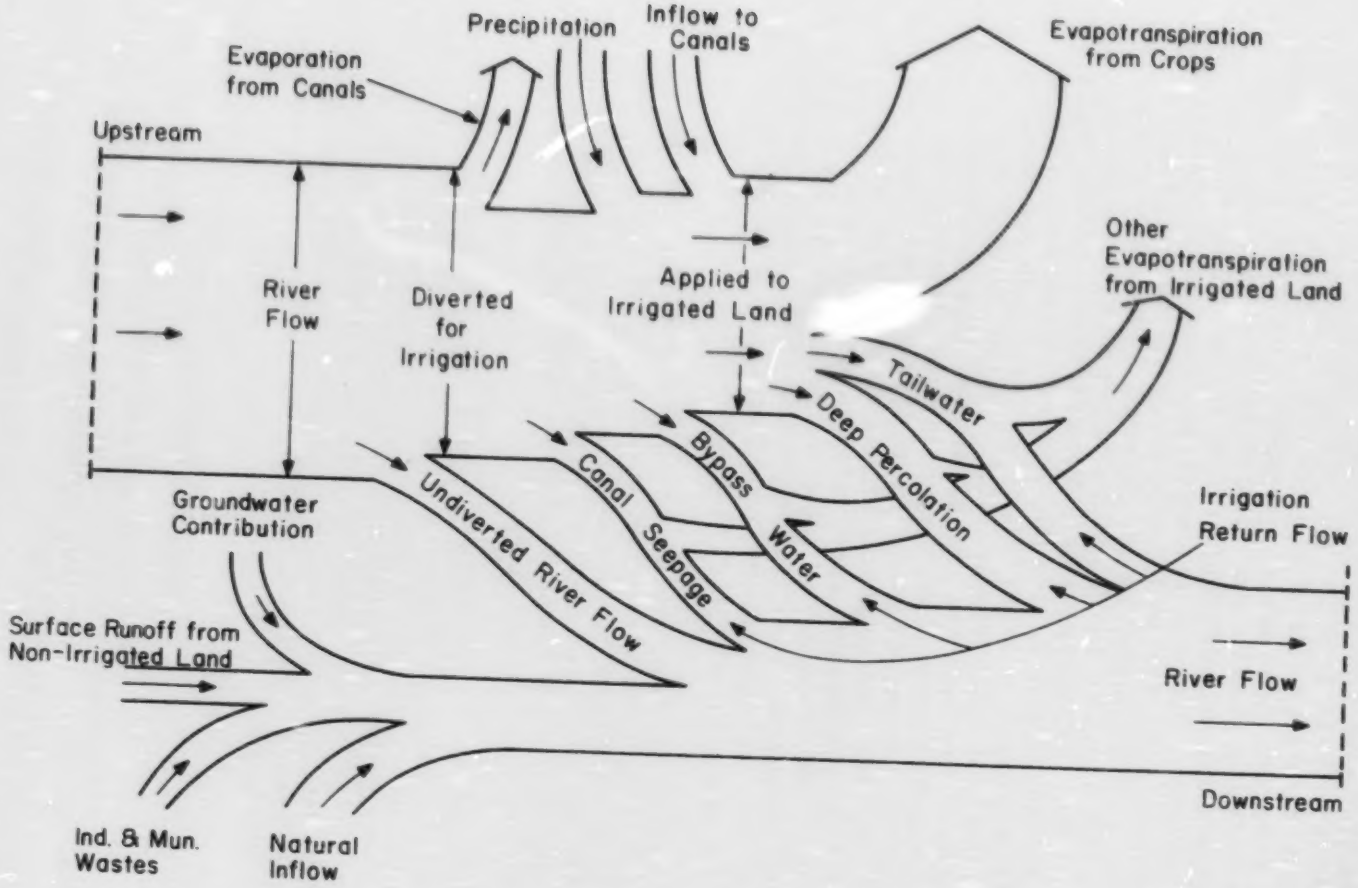


Figure 1. Conceptual diagram of the irrigation return flow system (after Skogerboe and Law, 1971).

Protection Agency. A joint research effort entitled, "Prediction of Mineral Quality of Return Flow Water From Irrigated Land," was initiated in May, 1969. This project was designed to first predict the mineral quality of irrigation return flows and then evaluate the impact such effluents could have on the remaining water resources in a river basin. Specific emphasis was placed on salinity in terms of its composition and concentration which would allow evaluation of specific constituents on downstream salinity. In order to evaluate the models developed, three case studies were investigated which covered a variety of environmental factors similar in range to those encountered in the western U.S. river systems. Verification trials were conducted in the Grand Valley in western Colorado, the Cedar Bluff Irrigation District in Kansas, and an area in the Vernal Unit of the Central Utah Project known as Ashley Valley. For each of these areas, the research involved characterizing field conditions, modeling to predict quality of percolating irrigation water, determining the effects of the percolation on local drainage effluents, and evaluating management alternatives on the quality of return flow. The product of this project was to be a set of verified mathematical simulation tools which could be used to evaluate the effects of existing and new irrigation activities on the quality of receiving streams.

Both the Bureau of Reclamation and the Environmental Protection Agency are concerned about the veracity of modeling efforts as applied to regional planning. Consequently, this workshop was organized and funded by this project to consider the state-of-the-art with a view towards standardization of modeling technology.

The extent to which this project may have accomplished a significant step towards such a goal is not known, but it did bring together modeling experts who deal with the problems associated with irrigation return flows. In the context of a workshop, these people were exposed to Bureau models, exchanged ideas with each other, and offered an initial assessment of the technology. This report summarizes that activity.

## PURPOSE AND OBJECTIVE OF THE PROJECT

The quality of irrigation return flows has become a matter of great concern in a number of areas where the high degree of water resource development leads to

substantial reuse of return flows. Specifically, in those regions approaching complete development of water, several locations may exist in which the flows are comprised primarily of upstream return flows. Improving the quality of a water resource where irrigation return flows are involved requires the identification and control of individual hydrologic segments transporting the pollutants. Due to the diversity in problem definitions and management strategies, interdisciplinary efforts are necessary.

The major objective of this project was to organize and conduct a workshop where individuals familiar with the various aspects of irrigation return flow models could critically review the work of the Bureau of Reclamation. Their models were not presented as the total answer to the long standing problem, but rather as one of the most recent efforts to integrate models concerned with irrigation return flows. Bureau models were, of course, intended to be sufficiently general in nature and scope as to be applicable to many different irrigated regions. Since model utilization would be aided by a critical assessment from professionals in and out of the government framework, this workshop was designed to accomplish the following objectives:

1. Provide a vehicle for interchange of concepts, methods, and ideas which will be useful in modeling irrigation return flows systems;

2. Introduce the USBR models to a wider audience of users;

3. Provide direct contact with the USBR modelers to explain the philosophy, theory, and applications of their models;

4. Provide a forum for assessing the present and future needs for modeling irrigation return flow systems; and

5. Stimulate an interdisciplinary awareness of the commonality of problems which must be addressed to manage irrigation return flow quality.

The participants invited to the workshop are listed in Appendix A. Two other guests not listed were Mr. John T. Maletic, Chief, Water Quality Office, Division of Planning Coordination, U.S. Bureau of Reclamation, and Mr. Robert Chandler, Graduate Research Assistant at Colorado State University. This group included Irrigation Engineers,

Drainage Engineers, Hydraulic Engineers, Soil Chemists, Soil Physicists and Groundwater Hydrologists. In addition, the participants came from a wide range of professional areas including university researchers, government researchers, and government administrators. The one thing common to each was extensive modeling experience and/or an interest in improving such capability.

## SCOPE OF REPORT

This report is intended to summarize the events, conclusions, and recommendations of the workshop. A comprehensive literature review of irrigation return flow modeling was compiled earlier in a report by the Project Officer entitled, "Prediction Modeling for Salinity Control in Irrigation Return Flows," (Report EPA-R2-73-168), and thus only selected abstractions will be made in order to support certain of the workshops events. Detailed user manuals of the USBR models are forthcoming, and additional details are described in existing publications so technical information concerning the models will be omitted. However, in order for the reader to also understand the Bureau of Reclamation's objectives and results, the abstract, conclusions, and recommendations from the summary report are included as Appendix B. The remainder of this report will include two sections. The first will address the ideas presented in the workshop through a discussion of irrigation return flow modeling. The second will be the author's summary of the workshop and views concerning the current state-of-the-art in irrigation return flow modeling technology.

## SECTION IV

## WORKSHOP ASSESSMENTS OF IRRIGATION RETURN FLOW MODELING

During the three day workshop five sessions covering three discussion areas were conducted. The first discussion area (Sessions 1 & 2) was provided to develop a common understanding of model philosophy, approaches, and problems associated with modeling irrigation return flow systems. The second discussion area (Sessions 3 and 4) was designed to provide a forum for the USBR modelers to describe and discuss their various modeling capabilities. The third and final discussion area (Session 5) was to provide an assessment of the USBR model efforts, exchange of modeling philosophy, and assess the immediate research needs to expedite development and utilization of models. The agenda for the workshop is presented in Appendix C.

### REVIEW OF IRRIGATION RETURN FLOW MODELING

Following the welcome of the participants and a statement of the objectives and format of the workshop, a brief review of the history of the existing USBR models was presented. A discussion on the structure of irrigation return flow models was then conducted to identify the multi-level nature of models and suggest further consideration in classifying existing models accordingly. After these introductory activities, seven of the participants presented their review of some of the important aspects in modeling irrigation return flows.

### Modeling Philosophy

A mathematical model in the context being used in this report may be loosely described as a set of mathematical expressions describing the complex behavior of the irrigation return flow system. Generally these mathematical expressions are coded in systematic computer language for actual use. Modeling is the art of formulating models, however, the only complete and true model of a system is the system itself. It should be emphasized that there is generally no unique model of a system since different models will be produced by different analysts according to their understanding and interpretation of the system. The models describing irrigation return flow systems are

generally simplified so that practical models can be developed to simulate this complex system. For instance, many hydrologic processes require simplification in order to find solutions to the mathematical relationships. Models of irrigation return flow systems are generally decomposed into interrelated subsystems or blocks. Each subsystem may be further subdivided into specific processes within the system with the aim of reducing the number of variables in each segment (Figure 2) to maximize flexibility and minimize inaccuracy. In constructing the linkages between various parts of the model, the relevance of each aspect should be examined closely.

Several attributes can be identified which stimulate the development of mathematical models. First is the utility of simulating a process, studying its response to a perturbation, and evaluating the results on the system without being constrained by using the real system or real time frame. And second, the ordering of natural processes into functional relationships in developing the model forces the modeler to detail, and thus understand the individual processes.

The system response generated by a simulation model can be used to evaluate the technical, legal, institutional, and socio-economic implications of a system management scheme. Thus, the answer to the question "Why model?" can range from a need to understand the primary mechanisms or processes occurring in a simple system to elaborate decision-making tools needed to manage a complex system. A model that is extremely useful for one user may be totally inadequate or inappropriate for another's need.

Although it is obvious that a model's utility and scope is limited by the modeler's knowledge of the system, there are other important constraints which dictate the extent to which a model may be refined and tested. For example:

(1) availability of data;

(2) accuracy of data;

(3) characteristic size of the system;

(4) characteristics of the mathematical statements composing the model; and

(5) computer capability and/or core storage requirements.

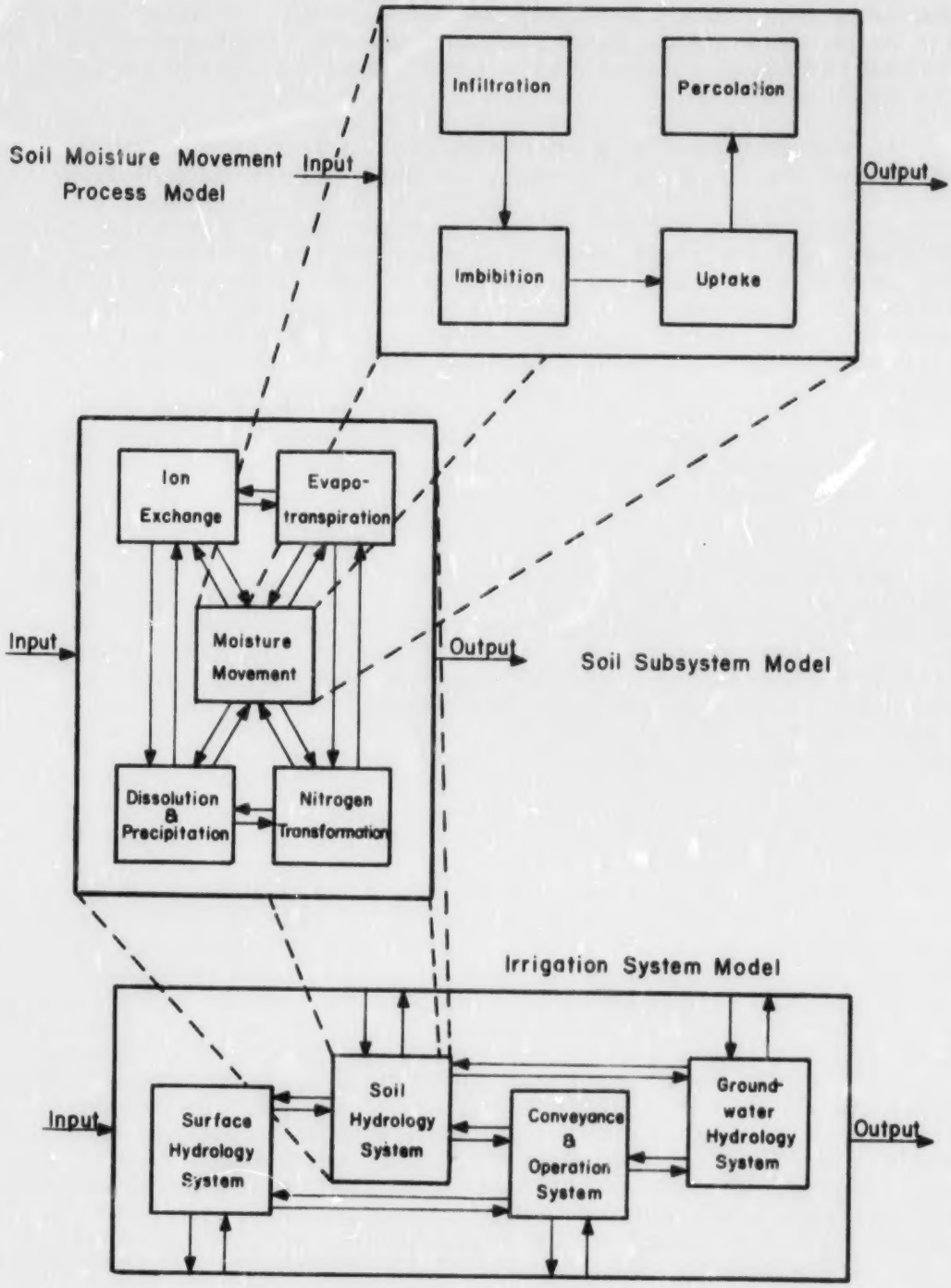


Figure 2. Conceptual diagram of block building in irrigation return flow modeling (after Hornsby, 1973).

Some of these limitations may be recognizable by only the most astute modeler. Thus the fact that a completely general irrigation return flow model does not exist merits mention.

In recognizing these factors, it is not difficult to understand why there are nearly as many models as modelers. In recent years, this situation has meant a great deal of duplication and a rather slow dissemination of the modeling advances. Although interdisciplinary research which has been touted for years may have significantly reduced duplication and increased information exchange, little has been accomplished, especially in irrigation return flow modeling. Today, as problems of water quality degradation associated with irrigation return flows become increasingly acute, the concerned research community cannot afford to "reinvent the wheel" for each problem area. The necessity for developing standardized model packages seems apparent although efforts to standardize may be impaired due to the complexity of nature.

During the workshop, participants were asked to respond to three questions regarding the above comments. Five choices were delineated in numerical fashion, ranging from 5 for strong agreement to 1 for strong disagreement. Values of 2 and 4 were for intermediate responses with 3 being neutral. A summary of the results of the questionnaires completed by the participants excluding both the writer and Project Officer is shown in Appendix D.

The first question was intended to assess the workshop participants' opinions concerning the numerous models that have been developed to describe irrigation return flow systems. When asked about the general availability of information concerning these models, 51% felt such information was unavailable for most potential users and only 16% felt otherwise. The general acceptance and use of other models was also considered poor by 50% of the group with only 8% having a positive reaction. An interesting view of the participants themselves and their interest in improving their own capabilities was indicated in three other responses under the first question. A desire to have detailed operational information about the existing models consisting of documented users manuals describing input requirements, methods of solution, operational characteristics, format of results, sensitivity to model parameters, and verification results was expressed by approximately 80% of the individuals. Since most of the participants are

actively involved in research supported by state and federal funding, it would seem important that attempts be made to provide these informational needs in order to improve the effectiveness of on-going and future research. In addition, the definition of certain terminology in models changes as research develops a new and better understanding of the physical processes and thus a system to centrally update the terminology would help as new problems come into focus.

The block building concept illustrated in Figure 2 is probably the best way of overcoming problems associated with using the many existing irrigation return flow models. Several other scientific professions have already taken steps to standardize some of the more commonly employed computational tools. For instance, most computer centers have both statistical and optimizational packages as part of their user libraries from which one can select a particular program to fit his specific needs. Of course, such libraries must not only be very well documented and verified but also written with a view towards use on various kinds of computers. Each program in the library must have the capability of being updated as new methods become available. Most of the workshop participants thought that such a program library would narrow the gap between research and application.

Question number three in Appendix D evaluated the participants' attitudes towards the idea of a central library of irrigation return flow models. The goal of one generalized, all inclusive model was rejected by 84% of the responses with 59% strongly disapproving. Most agreed that such a model may be useful but would be so large that many computers could not accommodate it and updating would be difficult. An alternative to the generalized model would be a set of generalized subsystem models, such as surface hydrology, root zone, groundwater models, etc. This idea would be similar to a library of second level models such as the soil subsystem model in Figure 2. The response to this idea was 33% strongly in favor, 33% slightly in favor, and 17% disapproving. It is apparent that even at the subsystem level, generality would be difficult. In addition, within such a subsystem there is research and application by more than one discipline, and a need exists to further subdivide these systems and allow modelers to formulate specific subsystem models for individual circumstances. The subdivision of subsystem models would consist of a library of subroutines and functions simulating individual components of the irrigation return flow system. This

suggestion is represented within the third level of Figure 2 (individual segments of the soil moisture movement process model). This question drew the most positive response from the group (75%) with 50% in strong agreement. Although one session of the workshop was devoted to discussing this concept, most of the participants needed more time to consider what the process level models might include. A partial list included potential evapotranspiration, infiltration, root extraction patterns for moisture and nutrients, horizontal and vertical unsaturated flow, saturated flow, ion exchange, mineral dissolution and precipitation, nutrient transformations, and various irrigation system characteristics. Some of these processes would require alternative methods of solution so several process models describing the same phenomenon would need to be developed. For example, calculation of potential evapotranspiration can be facilitated by numerous methods depending on climatic data, geographic location and desired level of fine tuning. There was some concern about matching time intervals and data requirements since some process models vary in each respect.

Based on the assumption that a library of process models could be developed and documented, a congruent set of programs representing the various formulations of subsystem models was discussed. Such subsystem models might include one of the irrigation system, crop system, root zone system, and groundwater system. Combining two or more subsystem models and possibly a mixture of process and subsystem models would lead to programs utilized in the field to evaluate the various irrigation return flow systems. And finally, combinations of the previously noted models could be utilized for the basin-wide models needed to evaluate the effects of different management alternatives. Thus, a four level program library was felt to be an important step in furthering interdisciplinary research and specifically attacking irrigation return flow quality problems in the future. Although various members of the workshop expressed concern over a number of potential problems, it was agreed that such an effort would require substantial time and funding as well as close coordination among modelers.

## Formulating Irrigation Return Flow Models

The third session of the workshop involved seven short presentations discussing the current status of various aspects of irrigation return flow modeling and where unsolved

problems may be encountered. After this session, all of the participants were asked to rate components of irrigation return flow models for adequacy and degree of development for general applicability. A summary of responses is found under question 2, Appendix D. Some of this information is interesting in view of the multidisciplinary nature of the group. Concerning models which describe the efficiency of individual irrigation systems as affected by field, soil, and crop characteristics along with climate and irrigator practice, 41% of the participants felt such analyses were currently inadequate while 16% disagreed. Models evaluating evapotranspiration, unsaturated flow, saturated flow and drainage, and surface hydrology and routing, however, were considered adequate by 67%, 42%, 50%, and 57%, respectively. Models of root moisture extraction and root zone chemistry were rated evenly with respect to adequacy as 25% responded both ways to each model. Other models felt to be inadequate were plant chemistry (64%), saturated zone chemistry (33%), and management and optimizational models (50%). In each of these ten categories of models, a substantial fraction of the participants was non-committal. This would tend to exemplify the various backgrounds present where certain kinds of models would not be of great familiarity. The specific interests of the group as a whole were indicated in question four when asked which of the aspects of the model of conjunctive use and regional water quality similation prepared by the USBR was of the most interest personally. Most were interested only in the mechanisms immediately surrounding the irrigation return flow system itself rather than how these flows reacted in the total river basin context. The results of these responses indicate some unfamiliarity with aspects of irrigation return flow modeling lying outside individual experience and interest.

As part of the workshop experience, it was felt that the seven individual presentations would aid the group as a whole in visualizing this problem in its entirety. The first presentation by Dr. Robert W. Hill concerned modeling irrigation efficiency, an area the questionnaire identified as inadequate at present for modeling irrigation return flows. Many models which attempt to describe irrigation have been developed for large valley or river systems. Such models are generally inadequate in assessing the effects that the irrigation system itself has on subsequent return flows. At the farm level, the measure of irrigation impact is termed irrigation efficiency which represents the fraction of water diverted for irrigation that is utilized by the crops. Specific subsets of irrigation efficiency such as

farm efficiency and application efficiency have been defined to segregate return flows into field tailwater and deep percolation. One of the most important parameters affecting efficiencies is application uniformity, or the uniformity with which water is added to the root zone. From a distribution standpoint this variable is difficult to define particularly for furrow irrigation cases. However, application uniformity is highly dependent on soil and field variability which to date has not been successfully simulated.

Water infiltrating the soil surface enters a two to five foot zone of soil where the bulk of crop roots are located. The total water extracted from this zone is dependent on plant characteristics and the soil moisture status, but is reasonably well estimated by examining the energy balance at the surface. The patterns of root water extraction were the subject of the second discussion by Dr. R. John Hanks. To date most models of the soil profile have either assumed moisture is taken up uniformly or taken up in decreasing fractions with depth. However, the time root uptake patterns are known at least to be non-linear, distributed and change with the irrigation season. An equation was presented describing the best current estimate of uptake and root growth (Nimah and Hanks, 1973a, 1973b). Recent research indicates that relative crop yields in terms of dry matter are related to relative transpiration (Hanks, 1974). Thus, accurate description of root uptake is not only important in simulating root zone moisture movement, but also in evaluating the effects of various irrigation practices on yield. In some cases, therefore, it may be important to consider the daily distribution of evapotranspiration. Also, with the increasing use of trickle irrigation, it is becoming more and more important to be able to delineate the crop transpiration from the soil surface evaporation. Most empirical estimating procedures include a crop coefficient to correct for physiological plant characteristics, and the effects of canopy cover on soil evaporation, but because of changes in the volume of soil wetted under low-tension, high-frequency irrigation systems (especially trickle irrigation systems), additional work may be required for predicting evapotranspiration under such irrigated systems. A useful reference on evapotranspiration was published by the American Society of Civil Engineers (Jensen, 1974). The modeling of root extraction patterns is also constrained by lack of an adequate predictive model for root growth-root activity as a function of time and space. A list of references presented at the workshop on the subject of plant root extraction of water

and solutes is given in Appendix E. Moreover, there are some questions on the relationships between relative yields and salinity concentrations in the root zone. Research is currently underway to help find answers to this question (Childs and Hanks, 1975).

The chemical characteristics of solute transport in the root zone and soil regions below the root zone was the topic discussed by Dr. Marvin Shaffer in the third presentation. A typical model of this system might consist of the following principal parts:

(1) Nitrogen. The nitrogen added to or found in soils undergoes such transformations as hydrolosis of urea; mineralization of organic nitrogen; immobilization of ammonia and nitrate; and nitrification. Rates for these reactions generally tend to be slower than soil chemical reactions and may be handled by a kinetic approach. The possibility of modeling nitrogen kinetics with what was called a transition state approach was introduced.

(2) Inorganic chemistry. The bulk of salinity in soil and irrigation supply water and return flows is almost exclusively derived from chemical weathering of rocks and minerals. Thus, solubility of minerals is a major chemical reaction. Other chemical reactions including cation exchange, formation of ion pairs, and bicarbonate buffering are also important considerations in soil and water chemistry. Since these types of reactions take place relatively fast, a chemical equilibrium approach is generally used to model these parameters.

(3) Constituent redistribution. Since moisture is being extracted by roots and percolating into or out of the root zone, an important aspect of modeling soil chemistry is predicting the movement and redistribution of salts and nitrogen.

During this discussion, a concept of layered segments in the soil system was presented as a method of computing the changes in root extraction and soil properties with depth. In outlining the primary chemical reactions which must be considered in western soils, the kinetic and chemical

equilibrium approaches to simulating these reactions were also discussed in terms of irrigation. The need for additional data to further refine modeling capability for mineralization, immobilization and denitrification seems to be the most critical area for further research.

The capability to simulate the unsaturated movement of water, salts, and nutrients in the soil profile gives some interesting alternatives for controlling the salinity stemming from irrigation return flows.

In the fourth presentation by Dr. James D. Oster, field and lysimeter data were presented to show the various techniques for managing the soil chemical system. Interestingly enough, the suggestion was made that salinity distributions in the soil profile are primarily a function of the irrigation system itself. Recent studies have shown that very few natural waters will cause yield reductions if leaching fractions are greater than 10%, and in some crops like alfalfa, the leaching fraction may be as low as 3%. The mass emission of salts from irrigated lands can be controlled to some extent by irrigation management, more specifically, controlling the leaching fraction. Two primary factors are involved, namely, salt pickup and salt deposition. Salts are picked up by chemical weathering of minerals and solubilization of soluble salts primarily as a function of depth of water passing through soils and chemical characteristics of the irrigation water. A reduction in leaching fraction generally results in less salt pickup, but as dissolved salts in the soil solution are concentrated by evapotranspiration, there is a tendency for calcium and magnesium salts to precipitate out as their solubility product constants are exceeded. Thus, a reduction in the leaching fraction may result in more deposition of these salts, and sodium will tend to predominate even while the salt content of return flows may be reduced. The overall resultant effect from minimum leaching is often an increase in salt concentration but a decrease in the mass emission of salts. It should be noted that these factors must also be viewed in conjunction with salt displaced from saline soil and aquifers underlying many irrigated areas. As less irrigation return flows are contributed to groundwater basins, less of the saline water from the aquifer will be displaced into receiving waters, and initially at least, little change in salt concentration would be noted. In addition, a reduction in irrigation return flows may also result in reduced rates of salt pickup from these saline

aquifers. The end results are difficult to predict because of the complex interaction between irrigation return flows and salt pickup.

The modeling of groundwater and drainage flows associated with irrigation systems, as reviewed by Dr. A.W. Warrick, comprised the fifth presentation. Most surface and sprinkler systems can be treated as one-dimensional flow patterns in both the root zone and soil or aquifer beneath. The analysis of one-dimensional moisture flow can be adequately determined using various mathematical procedures such as finite difference techniques, but the simulation of two- and three-dimensional flow patterns encountered under trickle or subsurface irrigation systems are generally more difficult. The studies reported have employed one-, two-, and three-dimensional programs using transient and steady-state solutions. Groundwater models were also reviewed including those incorporating groundwater chemistry options, a bibliography of which is listed in Appendix F. In any of these cases, the spatial variability has not yet been accounted for in either hydraulic parameters or input data. The discussion reviewed some of the most important studies evaluating the interfacing of unsaturated and saturated flow models. A problem that arose several times during the workshop was that there is difficulty in matching models with data in many aspects of hydrologic and water resource systems. Often the analyses generated by a computer are deemed infallible when, in fact, basic limitations and sources of error have been ignored. The results are conclusions which can be incorrect, and since many of the results of models are involved in significant legal decisions, the criterion for judging model accuracy is an important issue. Most of the group felt that one-dimensional description of flows below the root zone was adequate for modeling purposes, although dispersion and some two-dimensional flows must be considered under certain circumstances. An observation was made during this session that the chemistry models were sometimes more accurate than the associated moisture flow models except where nitrogen may be concerned. Since the chemistry model depends on accurate simulation of the moisture movements, some emphasis should be given to using reliable moisture flow models as a means of improving the overall capability to predict the quality of irrigation return flows.

The previous five discussions reported detailed information concerning the formulation of irrigation return flow models. In the sixth presentation by Professor Kenneth K. Tanji, some thoughtful and timely remarks were presented

on the application of the largely research oriented models to local and regional problems. During the past twenty years or so, most of the concerted effort by engineers and scientists has dealt with modeling small-scale irrigation problems. The models that evolved were primarily research submodels, and the utility of employing them for river basins, irrigation projects, and other large-scale systems has been questioned. As alluded to earlier, very few small-scale models have been verified in large-scale applications. Three primary reasons were identified for this observation. First, lack of adequate field data appears to be universal for broad-scope models. For example, the models of surface hydrologic processes are well supplied by climatic, land use, and stream gauging data whereas the subsurface hydrology is generally inadequately defined spatially and with time. Groundwater hydrology models encounter deficiencies with data used to estimate storage capacity, water and salt inputs from the unsaturated zones above, and the transient mixing at the unsaturated-saturated zone interface. The second consideration is the high level of refinement advanced in chemical simulation models. There is an inconsistency involved in applying such finely-tuned submodels to field conditions where spatial variabilities and lack of detailed characterization of soils and substrata materials constrain such models to somewhat simplistic analyses. A question of how much field data would be required to alleviate this inconsistency is not known. It is apparent that the crop root zone data are much more abundant than that for deeper underlying regions. An example of a problem resulting from this disparity of data is the paucity of information available on salt pickup and deposition from the natural geologic sources. And finally, most modeling efforts attempt to simulate the transient condition of the natural system. These short-term predictions at times tend to reflect the initial conditions rather than improved management conditions. Thus, water quality objectives may be more meaningfully met through the steady-state approaches in order for the results to better reflect long-term conditions. The detailed analyses of selected segments of an irrigation return flow system are well-founded but are limited in terms of practicality to large-scale uses, and perhaps simpler models should be used. Certainly simpler models are more compatible in many cases with available field data. Most of the participants also agreed that field applications and studies require time periods of five years or more which is generally not the practice today.

In the final presentation by Dr. M. Leon Hyatt, thoughts and discussions as to how the use of a systems analysis approach in modeling might be implemented were presented. The thorough and thoughtful planning required for effective salinity management must be coordinated with the goals and needs of the public at large. The various consequences of manipulating systems to affect management objectives will incur difficult political, institutional, and social constraints. At the beginning of efforts to implement improvements, or to implement existing or future public laws, the best technical input available will be required regardless of the level of refinement. Management level models must be basin-wide in scope because of the tradeoffs between various potential areas of development. In addition, the various state and federal agencies involved in water quality management need a range of modeling capabilities to specifically suit their needs. An outline summarizing the concepts requiring consideration when using a systems approach for basin-wide salinity management was presented. This outline as given at the workshop is as follows:

A. Modeling Salinity Systems
    1. Designating Appropriate Variables
    2. Delineating Relationships Among Variables
    3. Setting the Model Complexity
        a. Accuracy
        b. Management Questions
        c. Data Availability
        d. Variable Identification
        e. Solution Methods
    4. Understanding the Dynamic Nature of Salinity Systems and Associated Problems
        a. Equilibrium or Steady-State Conditions
        b. Time Increment
        c. Non-steady State Condition
        d. Data Limitations
        e. Type of Definition Required--Processes to be Looked At
        f. Extreme Events
    5. Conservation of Mass in Salinity System
        a. Data Limitations
        b. Events or Processes to be Described
            i. Hydrologic
            ii. Salinity Including Diffuse and Point Sources
            iii. Municipal, Industrial, Agricultural, and Other Natural Events

c. Consideration of Both Surface and Subsurface Waters
d. Size of Spatial Units in Basin
e. Incorporation of Subroutine Elements (other Models)

6. Consideration of Instream Flow Uses
   a. Fish and Wildlife
   b. Recreational

B. Methods of Modeling
   1. Optimization
   2. Statistical
   3. Mathematical Simulation
      a. Focus of Workshop Participants
      b. Difficulty of Verification

The basic physical and chemical characteristics of a river basin must be defined to at least some degree before planners and policy makers consider the political, institutional, and social problems associated with water quality management. Models provide a tool to evaluate management options. Depending on their complexity, relative effects of different options can be evaluated even though insufficient data may be available to verify the accuracy of a model in its ability to predict a current condition. Often planners will have to balance the need for a better simulation of a situation against the time available for a decision to be made. Consequently, many different models may be developed for a given situation, and the modelers and planners will wish to assure themselves that the concepts upon which the model is based make use of basic principles as well as the physical and chemical characteristics of a river system. In addition, models may also indicate what data should be collected in order to refine planning strategies.

## COMMENTS ON THE USBR MODELS

The USBR model development program with EPA funding evolved into two distinct phases. The first was the formulation of a river basin conjunctive use model, and the second involved a series of interfaced detailed models of the irrigation return flow system.

### USBR Conjunctive Use Model

The USBR conjunctive use model was designed to assess the water management alternatives on a river basin scale.

The functional operation of the model divides a hydrologic system into subunits called "nodes" which generally conform to the subbasins in an area identified by natural watersheds and U.S. Geological Survey gauging stations within each node. The delineation of flows is as illustrated in Figure 3. As one can readily see, the model considers the vast array of water uses in a river system. The workshop participants were given the opportunity to comment on model details and the Bureau's attempts at model verification.

In a previous section, the interests of the various workshop participants with regards to various segments of the model were presented. However, in questions 5 and 6 of Appendix D, the participants were asked for more specific responses to the model itself. The model obviously attempts to integrate the interests and expertise of several disciplines, and the group was asked to cite their opinion of the model's usefulness to them in accomplishing certain objectives. The first use of the model presented was in indicating the impact of an irrigated area on the total flow system. Sixty-two percent (12% strongly) felt that they could effectively use the model in this regard, and 38% gave a neutral reaction. No negative reactions were expressed. Approximately the same result was obtained concerning a question on using the model for regional water quality planning since the USBR has already utilized the model for environmental reports on a number of new irrigation developments. The Bureau will undoubtedly use the model in future environmental impact statements for proposed water resource developments, irrigation or otherwise, as required (63% felt they could utilize the model in this manner). The capability of scaling the results generated by the model in a small study area to a large one was disagreed upon. Twenty-five percent felt it would be of little use to them while 12% responded positively and 63% reacting neutrally. The conjunctive use model probably was not intended for a small study area because data and results are generally more explicitly defined. An interesting point was made by the USBR personnel present concerning the coordination of the basin scale model with the highly scientific models of the individual hydrologic segments. Using available data which was noted earlier as generally insufficient for the detailed models, the conjunctive use model could perform a "first cut" analysis and give valuable qualitative results. For example, this model could identify critical irrigated areas where further data could be collected for the detailed model in

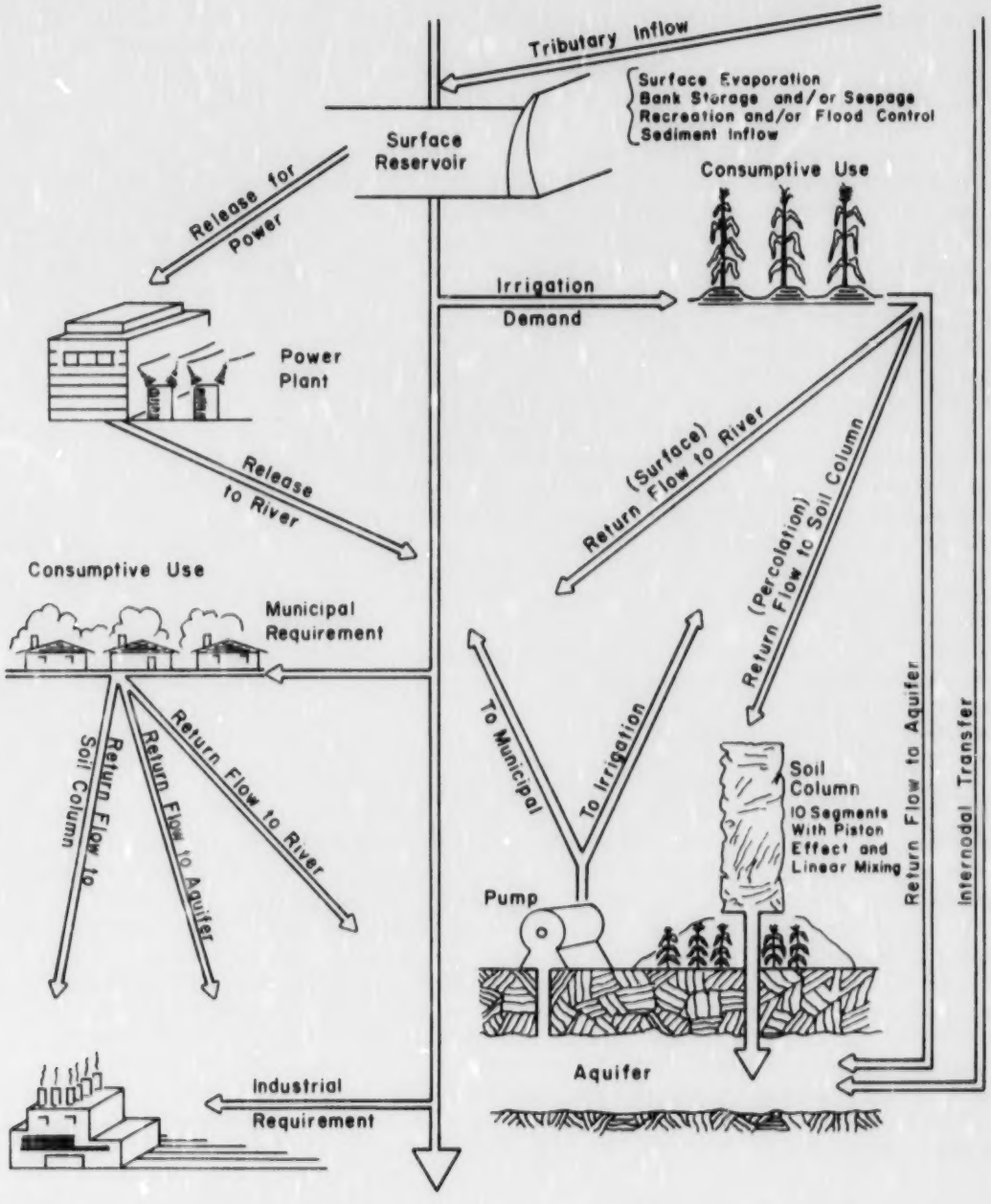


Figure 3. Illustrative flow chart of the USBR conjunctive use model.

answering specific questions. Thus, the concept of using higher level models as planning tools should be considered for analysis of interactions of complex phenomenon, identifying important hydrologic variables, and delineation of data collection requirements. In fact, the third item in question 5 asked just how the participants felt about such a use and 50% felt favorably towards this concept. The use of the conjunctive use model as an irrigation return flow model and one capable of evaluating other models was not endorsed. Only 25% felt mildly that such use could be made and 25% felt otherwise.

The data necessary for the conjunctive use model comes from different kinds of monitoring systems or studies, all of which have varied objectives, accuracy, and time interval characteristics. The group was invited to assess the resolution of these factors keeping in mind the model's purpose and scope. In simulating the irrigation return flow system itself, 50% felt the model's use of soil moisture movement data was inconsistent, and 25% agreed also in the area of soil chemistry. In both cases, 25% and 37%, respectively, reacted in reverse. Thus, in the soil environment itself, the model could be improved by updated mathematical concepts and by better coordination between the soil moisture movement simulation and available data. The highest ratings for inconsistency were given to groundwater movements and chemistry. In handling of groundwater movement, where it was noted earlier that data are severely limited, 50% of the group disagreed with the modeling approach with 12% strongly disagreeing. At the same time 12% felt mildly in the opposite vein. The simulation of chemistry in the groundwater received a negative rating of 76%. The conjunctive use model was rated favorably in the segments describing surface distribution of irrigation diversions, consumptive use, and reservoir operation and chemistry.

The conclusions which stem from this phase of the workshop are as follows. The conjunctive use model is well suited to assessing the potential impact of irrigation developments and in giving overall planning direction in the use of the detailed irrigation return flow model. The use of this model as a tool to consider existing irrigation return flow systems or to verify their models is not recommended. This agrees with the intent of the personnel who developed the model, namely, to design a model for the evaluation of irrigation return flows rather than to design

a model which details the flow itself. Other comments were detailed directly under question 11 and 12, Appendix D.

## Detailed Irrigation Return Flow Models

The second aspect of the USBR models deals with detailed simulation and prediction of return flow quality. The models simulate the plant-soil-water system encompassing the region between the soil surface and the area of a groundwater return point such as a tile or open drain. The flow of this system is illustrated in Figure 4 and consists of separate models for evapotranspiration, unsaturated and saturated water flow, dissolution-precipitation of slightly soluble salts, cation exchange, ion pairing, nitrogen transformations and uptake by crops, and the movement and redistribution of salts and nutrients. This interfaced system allows a dynamic nonsteady-state approach to simulating the following specific chemical constituents: calcium, magnesium, sodium, bicarbonate, carbonate, chloride, sulfate, nitrate-nitrogen, ammonium-nitrogen, and urea-nitrogen contained in soil, aquifer, and drainage flows. Within the soil and substrata regions, organic nitrogen and gypsum concentrations are predicted along with exchangeable calcium, magnesium, sodium, and ammonium. These models and their verification were discussed during sessions 3 and 4 of the workshop.

Most of the workshop participants were interested in the recent improvements in modeling unsaturated zone chemical behavior. The flow of water, salt, and nutrients in this zone of the soil was modeled with a revised version of the model presented by Dutt and Shaffer (1972), which several of the participants had actually helped formulate or were familiar with its functions. As the discussion proceeded, several suggestions were made for future improvements and were first solicited in question 7, Appendix D. The distribution of water under different irrigation regimes was considered an area for improvement by 62% of the responses while 38% disagreed. The rapidly expanding use of trickle irrigation and, in fact, the entire concept of low-tension, high-frequency irrigation would seemingly require such improvements to accurately depict the chemistry in the first few feet of the soil. Nitrogen chemistry seemed to be another area of major concern of the group as illustrated by the 50% rating given to suggesting its improvement with only 25% in disagreement. The same

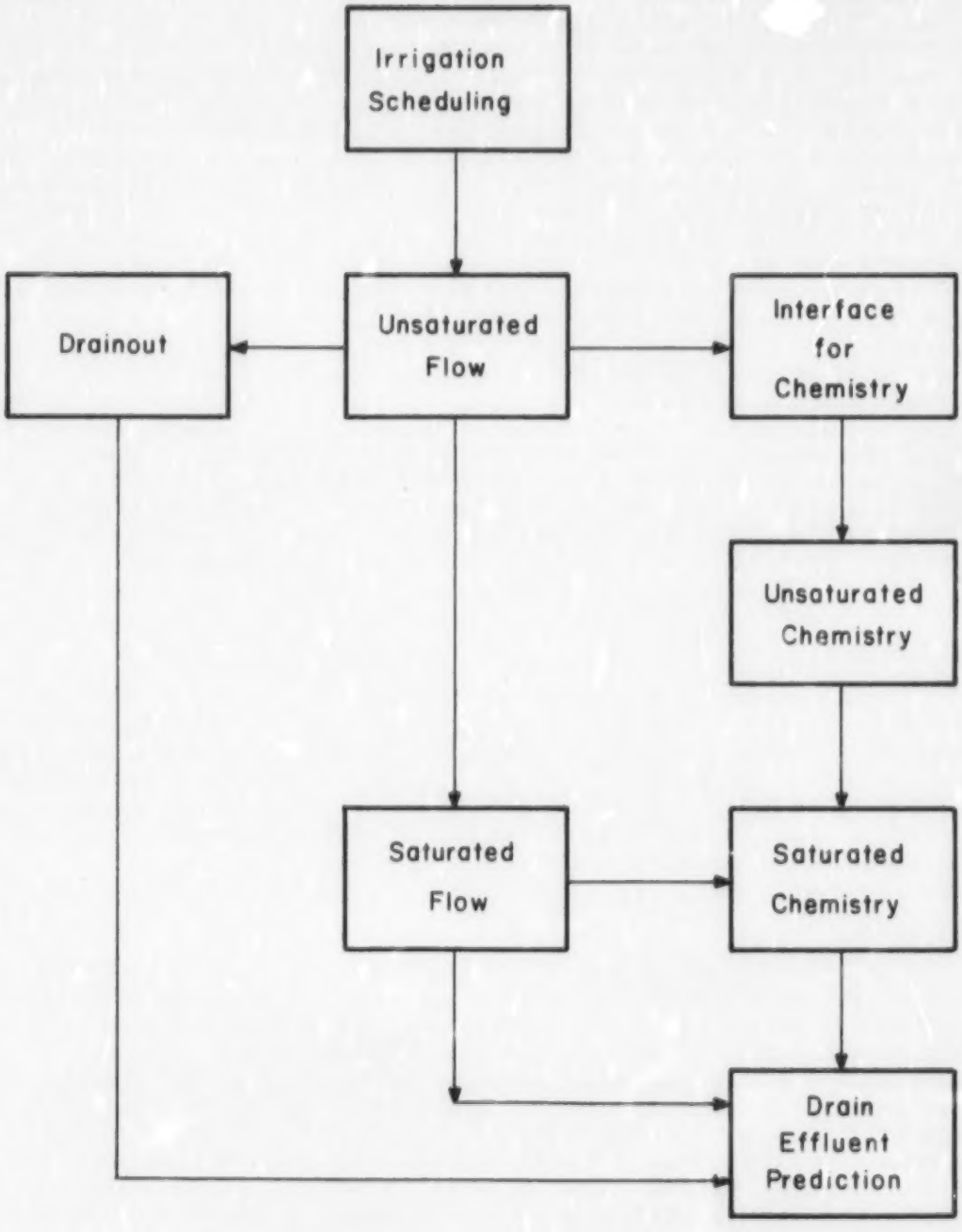


Figure 4. Flow chart of USBR detailed irrigation return flow modeling system.

response also applied to predicting other nutrient and fertilizer movements, root extraction patterns, and estimation of evapotranspiration. Overall, 63% felt continued efforts should be made to enhance the model's capability to simulate salt movement, exchange, and reactions in the soil. This overall question may seem critical in identifying weaknesses in the unsaturated chemistry model although the workshop atmosphere was otherwise. Most felt this model was good, and the suggestions were intended as guidance for whatever additional changes may be forthcoming. Question 8 asked of the participants whether they would consider interfacing this model with their own. Fifty percent reacted strongly in favor, while 75% indicated this model is useful to their on-going or anticipated research. From a purely technical standpoint, the exposition of the unsaturated chemistry model may have been the most beneficial result of the workshop.

The saturated flow and chemistry models also received considerable interest from the group although these models are oriented primarily towards drainage design and evaluation. Again, 50% of the participants rated the model's utility favorably, while 12% had little current interest.

## General

The overall assessment of the USBR models was positive by most of the workshop participants. Their evaluation of the conjunctive use model indicated several problems to which it should be readily applicable and certain instances where its utility would be limited. The interest in the detailed models was also significant. There were, of course, suggestions for improvement of a qualitative nature that were determined by the questionnaires and during the discussions.

The USBR models are structured in a subroutine format that most believe is the most feasible method of modeling the irrigation return flow system. Since various participants were not experienced in the terminology of each subroutine function, they were asked if sufficient detail had been given for a user to determine when it is appropriate to use a particular subroutine. The majority who did comment indicated sufficient detail had been given, but a substantial effort must be made in each case to understand the actual workings of the models. In order to maximize the utility and reliability of USBR models, the following specific suggestions were made:

1. Conduct more sensitivity studies to determine the effects of field data variability, model assumptions, and model resolution in time and space;

2. Reevaluate the methods of simulating groundwater movement and chemistry to include salt pickup, saturated flow conditions where a drainage system is not present, anisotropy, and increased emphasis on two-dimensional flows; and

3. Update the unsaturated flow program to improve simulation of bare soil evaporation, root extraction patterns, layered soils, and hysteresis effects.

There were also various comments suggesting changes in USBR techniques which are found under question 6, Appendix G. The reader may wish to read these himself for any implications that are present.

## SUMMARY AND FUTURE DIRECTION

The final session of the workshop was a summary and general discussion period in which problems in irrigation return flow modeling were discussed and suggestions made for future research.

Discussion about the characteristics of data and their use in models reoccurred frequently at the workshop. As pointed out earlier, a substantial disparity exists between available data obtained from surface and subsurface elements of the hydrologic system and that required by adequate models. Thus when models are applied to systems involving irrigation return flows, errors and unknown variables tend to get lumped together in the groundwater because of the usual lack of groundwater data for verification and/or inadequate definition of subsurface hydrology. When this occurs, the model's ability to reflect the effects any water management policy may have on return flow quality is restricted by the assumptions regarding groundwater behavior. The participants indicated in a take-home questionnaire, Appendix G, what they felt were the important research needs. In question 4, responses a and e noted the groundwater modeling problems. The two points raised here regarded the acquisition of adequate data on groundwater hydrology and the investigation of the linkage between unsaturated and saturated flow regimes.

An important point raised during the proceedings was the observation that current theoretical developments are inadequate to treat the spatial variability of soil properties with a reasonable degree of confidence. In small-scale applications of return flow models, data may be much less variable than in large areas. An important research need is the definition of data requirements in modeling large tracts of irrigated land area. Soil mapping should be made in accordance with anticipated use of the data. Also, consideration should be given to additional analyses of specific parameters as an aid to both the verification and interpretation of computed results. For example, chloride ion in most western soils is not significantly adsorbed by the soil, and thus, the ratio of chloride concentrations in the soil solution and irrigation water may provide a reasonable check on deep percolation leaching of soluble salts or the concentrating effects of evapotranspiration.

Problems associated with "reinventing the wheel" in modeling were noted as substantiation of the need for formulating a standardized library of well documented subprograms in the field of irrigation return flow modeling. Responses to question 4 in Appendix G contain several references to improving calibration, increasing sensitivity and documentation, etc. A systematic and uniform program for coordinating modeling efforts would aid each of these needs. An additional need was noted for intermediate level models which would perform somewhere between the USBR conjunctive use model and their detailed irrigation return flow model. Again, the library concept would answer this need by having such models available so the building blocks for an intermediate level model could be readily assembled.

Maybe one of the most neglected parameters in models discussed was the influence of the design and operation of the irrigation system itself. Uniformity differences, for example, can result in corresponding differences in an irrigated field. A stronger emphasis is being placed on irrigation systems which maintain a uniform, low-tension, soil-water regime because some reported results have shown improved yields, higher quality produce, water and labor savings, and more effective fertilization (Second International Drip Irrigation Congress Proceedings, 1974). With these advances in this area, it may be necessary to characterize certain soil properties such as infiltration rates throughout the irrigation season to adequately model the moisture flow. The practices of the irrigator himself play an important role in determining how much moisture may

be applied to the soil profile. Irrigation efficiency has been used to describe the effectiveness of irrigation practices. Yet, recent studies have demonstrated that the concept of irrigation efficiency when applied to return flow studies may be misleading since these values vary widely during the irrigation season. Thus, the problem noted earlier concerning the problems of averaging data not normally distributed are present here as well. Finally, there is some evidence that the soil chemistry itself is highly dependent on the characteristics of the irrigation water and how it is applied.

It is anticipated that return flow models in the future will improve in reliability and accuracy, but the answers they give will remain basically the same from a management standpoint. Thus, future investigations should begin encompassing the detailed simulation models within the framework of an optimization analysis which may permit the expansion of evaluations from, "What will be the effect of an alternative policy for controlling the quality of return flows?" to "What is the best alternative?" The plans for managing water quality must be made with available modeling results because the legislative bodies have so demanded. However, without the added analysis of optimization, it will be difficult to identify the most cost-effective alternative.

As the return flow programs evolve from the investigation to implementation stage, there are several problems to be solved. First, funding and time limitations will require that the most relevant parameters, which vary from one site to another, be defined for the operation of these models. This will necessitate performing many of the sensitivity and library suggestions made during this workshop. Secondly, the continual changes in certain concepts, which occur from a better understanding of the system, or in the physical elements themselves, require some level of basic support. And finally, the science and art of irrigation return flow modeling is probably not completely bridged by any single individual. Thus, the models and analyses developed and reported can easily be used inadequately. In each of these three areas, it would be helpful if a text or manual were available which considered the various guidelines relevant to data collection and model analysis of field conditions. A proposed table of contents was prepared by the Project Officer and discussed by the workshop participants. Most agreed

to consider the outline, make suggestions for its improvement, and cooperate at such time as such a document may be written.

## SECTION V

## WORKSHOP SUMMARY

Although a certain amount of summarizing of the workshop has already been given, there are two additional areas that should be discussed in order to complete this report. At the conclusion of the workshop, the participants were given a take-home questionnaire designed to assess the contents and operation of the workshop. These results are presented in Appendix G. And after working with the USBR models, conducting the workshop, and observing its results, the writer feels several comments are in order.

### PARTICIPANT ASSESSMENT OF WORKSHOP

The first question on the take-home questionnaire invited the participants to evaluate how well the workshop accomplished its goals. All of the participants felt the workshop objectives concerning the USBR models were met. Specifically, two of the project objectives were to introduce these models to the group and provide the contact with USBR personnel to explain their philosophy, theory, and applications. The goal of providing a vehicle for interchange of concepts, methods, and ideas useful in the modeling of irrigation return flow systems was generally viewed as an important accomplishment of the workshop. But, a couple of the participants felt this objective was not fully met because of a high degree of commonality among the participants. Another stated objective--the stimulation of an interdisciplinary awareness of the problems which must be addressed in irrigation return flow analysis--was considered met by most of the participants. The one objective receiving the widest variety of responses concerned providing a forum for assessing the present and future needs in this area of modeling. Most agreed this goal should have been given more time and emphasis during the workshop.

The second question noted that topics were covered which were outside the scope of most individual interests. The group was invited to point out the degree to which the association with people of varied interests expanded their own perceptions. All of the responses indicated that the workshop had facilitated this to some degree. In general,

most found they had learned possible new approaches to problems they had encountered in their previous work. There were those who benefited by the broad dimension of interest represented at the workshop and thereby gained a better understanding of the various philosophies being applied to modeling irrigation return flows. Of course, the people present were a good source of references for potential problems that may occur in some future work, and the participants were pleased with the opportunity to associate with the USBR personnel.

The time, depth, and organization of the workshop were difficult factors to plan since there were no applicable workshops of a similar nature from which to judge. Most of the responses to a question asking for comments on these factors were positive. Some areas of the workshop that could have been given more emphasis include:

(1) Needs for future research. The discussion of research needs and future emphasis occurred at the end of the workshop when several of the participants were absent. The discussion, however, should have been more explicit.

(2) The discussions relative to a central program library could have been extended to investigate the structure more fully. Also, this discussion should have been at the end of the workshop after the USBR models had been introduced.

(3) Some participants could have benefited if more practical use of the models had been discussed, and in particular, the type of results generated.

Questions 4, 5, and 6 dealt with potential research topics (or problem areas) and comments regarding the USBR work, both of which were discussed previously.

Finally, the participants were asked for their frank opinions of the workshop. The responses in question 7 speak for themselves, but in general, most felt the workshop was worthwhile and productive.

## A PERSONAL ASSESSMENT

If the past twenty or thirty years of irrigation research and application are viewed closely, one finds an extremely rapid development of the technology in all its aspects. Each discipline has been so excited by the discoveries in their topic area and the questions remaining to be solved that little concern for the other discipline areas were considered in design or operational decisions. When the quality of return flows began imposing on the utility of the available water resources in a region, it soon became apparent that the problem and its solutions were very complex. At first, investigators studied within their particular scope, but as officials charged with remedying these problems insisted on suggestions for management and control, an integration of existing knowledge had to occur. An example of this integration is the modeling effort of the USBR and this interdisciplinary assessment. State and Federal agencies strive to coordinate research. A point is reached, however, when the technology generated by research shifts into the hands of state, local, and private groups charged with detailing and implementing a policy for pollution control. Obviously, analytical models which consolidate the concepts generated by research are going to be useful to those who define policy, and workshops are necessary steps in model development for these purposes.

Another important problem with regard to computer models is that they remain a deck of coded cards written in the style of its author and arranged to manipulate the computer as efficiently as possible. There are two problems that inevitably result. The first is the vast differences in the coding skills of individuals writing the programs versus those who use them, and the second is the variance among computers. In the latter respect, a good example is the USBR conjunctive use model. When it was submitted to the Colorado State University computer, basic fortran errors dealing with redefinition of loop parameters were encountered as well as indefinite operands, yet the USBR and CSU computers are made by the same company.

If most research and development budgets are examined, computer costs are a small fraction of the totals. When a great deal of time is spent on adding sophistication to the computer codes in the name of saving money, the

perspective of using models as a computational tool has been lost. In general, the cost of time spent to save a few dollars in computational time are poorly invested by those other than expert programmers.

The concept of an irrigation return flow model library will be unworkable unless the entries are coded in a manner that minimizes the alterations necessary to make the programs operational on other computers. In addition, the use of program logic must be straightforward if the many individuals from different schools of computer training can successfully implement the program in their own work.

In examining these points and the others raised during the workshop, the inclusion of other noted individuals to the list of participants would have been helpful. The available funding and facilities precluded additional modeling specialists, several of which indicated a desire to participate. Consequently, those who were invited were selected to sample the principal research and administrative areas. While the writer personally believes a better group of people could not be assembled, no offense to the many other people interested in irrigation return flow modeling was intended.

## SECTION VI

## REFERENCES


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## SECTION VII

## APPENDICES

A. List of Workshop Participants

B. Abstract, Conclusions, and Recommendations from USBR Summary Report

C. Workshop Agenda

D. Results of Workshop Questionnaire

E. Bibliography -- Plant Root Extraction of Water and Solutes

F. Bibliography -- Groundwater Quality

G. Results of Take-Home Questionnaire

## APPENDIX A

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## APPENDIX B

## ABSTRACT, CONCLUSIONS, AND RECOMMENDATIONS FROM USBR SUMMARY REPORT*

### ABSTRACT

This volume of the report outlines the purpose and scope of the return flow research and specifically explains the capabilities of the conjunctive use model for predicting the mineral quality of irrigation return flow. The purpose of the research was to develop a conjunctive use model which would (1) predict the salinity contribution from new irrigation projects and (2) predict the change in return flow salinity that would result from operational changes on existing projects.

The model developed and described herein describes the chemical quality in terms of eight ionic constituents and total dissolved solids. A nodal concept has been used to facilitate subdividing the project area along physical or hydrologic boundaries as desired. The study may be limited to 1 or as many as 20 nodes.

A description of the Vernal Field Study which describes the physical setting for the model testing is included. A narrative describing the problems encountered with the original data is included. A data collection program was initiated to fill the gaps. The model satisfactorily simulated the new 2-year data base. Tables and figures showing the computed-observed comparisons from the verification are included. Results of model operations for the Cedar Bluff and Grand Valley areas are also described.

It is concluded that the model can satisfactorily be used to simulate irrigation return flows if sufficient data are available, especially groundwater hydrology and chemistry.

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* U.S. Department of the Interior, Bureau of Reclamation, 1976. Prediction of Mineral Quality of Irrigation Return Flow - Summary Report and Verification. Reproduced for this Workshop by Special Permission from the U.S. Environmental Protection Agency. The complete set of five volumes may be acquired from the U.S. Government Printing Office or National Technical Information Service at the completion of the USBR-EPA contract.

The report was submitted in fulfillment of Project EPA-IAG-D4-0371 by the U.S. Bureau of Reclamation, Engineering and Research Center, under the sponsorship of the Environmental Protection Agency.

# CONCLUSIONS

This research was concerned with the development of procedures for predicting the mineral and nutrient quality of return flows from irrigation. Actual field conditions that typify irrigation development in the western United States were studied. In each study area, the research involved characterizing field conditions, applying computer models to predict quality of the percolating irrigation water, determining the effect of the percolating water on drainage effluent, and evaluating system changes on quality of return flow.

The percolation of water through soil in the process of irrigating crops results in very complex chemical relationships. Both the mineral and nutrient content and the quantity of return flow are difficult to predict under conditions found in irrigated agriculture.

In developing a predictive mathematical model to simulate the effect of irrigation on water quality, it was relatively simple to duplicate surface conditions. The complexity of the problem stems from not having sufficient knowledge of subsurface conditions such as soil chemistry, volume of groundwater, aquifer capacity, depth to barrier, and drainage characteristics. Variation in soil types within short horizontal distances makes the acquisition of this type of data costly, and it is not always available as needed.

This study dealt with three irrigated areas in attempting to verify the predictive conjunctive use model - the Vernal, Utah area; the Grand Valley, Colorado area; and the Cedar Bluff, Kansas area.

Adequate data were available for the Vernal area and the verification effort was minimal. Less data were available from the Cedar Bluff area with respect to the groundwater body, and the verification proved to be much more difficult. The chemistry of the return flow water is dependent to a large degree on the volume and chemistry of the subsurface water. Although the quality of the groundwater was well established, considerable adjustment of the groundwater volume was necessary in order to simulate existing conditions. This suggests that the primary requirement in the simulation process is to have a good knowledge of hydrologic conditions, including the groundwater body, and particularly to establish a hydrologic balance in the system.

## RECOMMENDATIONS

The complexity of the salinity problem as it relates to irrigated agriculture is borne out by these studies. The need for a mathematical prediction model to assist in understanding the salinity and nutrient problem is now more clearly evident. The usefulness of the model in simulating project conditions has been demonstrated, and its ability to forecast changes resulting from improved management has also been demonstrated in a limited way.

Although model development and testing have been hampered by the lack of sufficient data, confidence could be extended by the collection of additional data and testing the model under a variety of conditions. The two primary functions of the model are (1) to predict the salinity effect from new irrigation projects and (2) to predict the change in salinity that might result from operational changes on existing projects. Some further work should be undertaken, particularly on Item 2, since the results could be quickly monitored and since there is very little development of new irrigation projects underway.

Model development has demonstrated that data of good quality and quantity are the primary requirements in achieving a good simulation of irrigation project conditions. Another requirement would be a good basic knowledge of hydrologic conditions in the study area. If these elements are lacking, difficulty can be expected in simulation results.

A comparison of month-by-month observed and predicted values with the annual values in the various studies indicates that the predictions are more reliable on an annual basis than a monthly basis. Since a great many factors influence salinity levels on a monthly time frame, decisions related to salinity projections based on model studies should be limited to annual values.

APPENDIX C

MODELING WORKSHOP AGENDA

March 19, 1975

Session 1. Modeling Philosophy

a. Objectives of Workshop

b. Workshop Format

c. History Leading to Existing USBR Models

d. Position Paper on Structure of Irrigation Return Flow Models

Session 2. Formulation of Irrigation Return Flow Model Systems

a. Modeling Irrigation Efficiency by Robert Hill, Utah State University.

b. Modeling Root Extraction and Evapotranspiration by John Hanks, Utah State University.

c. Modeling Root Zone Chemistry and Nitrogen Movement and Transformation by Marvin Shaffer, Bureau of Reclamation.

d. Management of Root Zone Salinity by James Oster, U.S. Salinity Laboratory.

e. Modeling Groundwater and Drainage Flows Associated with Irrigation Systems by Arthur Warrick, University of Arizona.

f. Scaling Research Models for Application to Large Irrigation Systems by Kenneth Tanji, University of California at Davis.

g. Systems Approach to Managing Basin-wide Salinity by M. Leon Hyatt, U.S. Environmental Protection Agency.

Session Summary by Arthur Hornsby

March 20, 1975

Session 3. Irrigation Return Flow Modeling in the Bureau of Reclamation

a. Simulation of Conjunctive Use and Water Quality in a River System. A presentation of the USBR Conjunctive Use Model by Eugene Christafano, Hydraulic Engineer, Bureau of Reclamation.

b. Modeling Chemistry of the Partially Saturated and Saturated Zones. A presentation of the USBR unsaturated chemistry model by Marvin Shaffer, Soil Scientist, Bureau of Reclamation.

c. A presentation of the USBR unsaturated flow, saturated flow, and drainage models by Richard Ribbens, Hydraulic Engineer, Bureau of Reclamation.

Session 4. Discussion of Field Verification Trials

a. Case Study 1 - Vernal by Eugene Christafano

b. Case Study 2 - Cedar Bluff by Eugene Christafano

c. Case Study 3 - Grand Valley by Wynn Walker

d. Case Study 4 - South Montezuma Valley by Marvin Shaffer

March 21, 1975

Session 5. Workshop Summary and Review of Research Needs - Present and Future

a. Open group discussion.

## APPENDIX D

## WORKSHOP QUESTIONNAIRE RESPONSES

The following questions and statements were formulated to solicit comments concerning where we now stand in the topic area of irrigation return flow quantity and quality modeling technology. Responses were rated on a scale of 1 to 5, if the feeling that the question or statement was completely correct or if strong agreement was indicated, a 5 was written in the box at the right. If the reaction varied from quite negative to mildly positive, responses ranged between 2 and 4. This summary of the feelings of the workshop participants excludes those of the writer and project officer. The numbers presented for questions or statements 1 - 10 equal the percentage of responses falling into one of the five choices. In questions 11, 12, and 13, written comments were transcribed directly.

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| 1. Numerous models have been developed relating to individual or varied aspects of irrigation return flow systems. | | | | | |
| (a) How would you rate the general availability of information regarding these models? | 8 | 8 | 33 | 42 | 9 |
| (b) How much would you benefit from having information describing such models summarized into one or a series of reports or users manuals? | 25 | 58 | 17 | 0 | 0 |
| (c) How much would you benefit from a documented user's manual for these models describing input requirements, methods of solution, operational characteristics, and format of results? | 33 | 42 | 25 | 0 | 0 |
| (d) How much would you benefit from an assessment of the sensitivity of model parameters and results as affected by various kinds and qualities of input data? | 67 | 25 | 8 | 0 | 0 |
| (e) How would you rate the general acceptance and use of these models by those other than the author, especially those in other disciplines? | 0 | 8 | 42 | 42 | 8 |

2. The components of irrigation return flow models have been identified. How would you rate these components for adequacy and degree of development for general applicability?

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| (a) irrigation efficiency models | 8 | 8 | 33 | 33 | 8 |
| (b) evapotranspiration models | 0 | 67 | 17 | 8 | 8 |
| (c) unsaturated flow models | 8 | 42 | 42 | 8 | 0 |
| (d) root extraction models | 0 | 25 | 50 | 25 | 0 |
| (e) root zone chemistry | 0 | 25 | 50 | 25 | 0 |
| (f) plant chemistry models | 0 | 0 | 33 | 33 | 0 |
| (g) saturated flow and drainage models | 0 | 50 | 50 | 0 | 34 |
| (h) saturated zone chemistry models | 0 | 0 | 67 | 33 | 0 |
| (i) surface hydrology and routing models | 17 | 42 | 25 | 16 | 0 |
| (j) management and optimizational models | 0 | 25 | 25 | 25 | 25 |

3. Models of irrigation return flow systems have been formulated in a number of different ways depending on their use and the areas to which they are applied. Below are several ideas for increasing the use of existing models and concepts. What are your preferences?

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| (a) Development of one generalized, all inclusive irrigation return flow model. | 0 | 8 | 8 | 25 | 59 |
| (b) Development of a set of generalized subsystem models such as surface, root zone, and groundwater models, etc. | 33 | 33 | 17 | 9 | 8 |
| (c) Library of subroutines and functions simulating individual components of the irrigation return flow system, i.e. in the root zone having separate but standardized models for root extraction, infiltration, chemistry (soil and plant), percolation and evapotranspiration. | 50 | 25 | 17 | 8 | 0 |
| (d) Irregardless of your choice above, how do you rate the importance of documented field verification? | 75 | 25 | 0 | 0 | 0 |

4. The model of conjunctive use and regional water quality simulation consists of the following functions. How would you rate your interest in these functions?

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| (a) Reservoir operation and quality | 12 | 12 | 39 | 12 | 25 |
| (b) Hydro-power generation | 0 | 0 | 38 | 12 | 50 |
| (c) Irrigation related consumptive use | 25 | 63 | 12 | 0 | 0 |
| (d) Irrigation return flow | 63 | 25 | 12 | 0 | 0 |
| (e) Soil water movement and chemistry | 63 | 25 | 12 | 0 | 0 |
| (f) Groundwater movement and chemistry | 50 | 25 | 13 | 12 | 0 |

5. Because the conjunctive use model integrates the interests of several disciplines, how would you assess the model's usefulness to you with regard to the following statements?

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| (a) Indicating the impact of an irrigated area on the total flow resource. | 12 | 50 | 38 | 0 | 0 |
| (b) Scaling the results of a small study area to an entire irrigated area. | 0 | 12 | 63 | 25 | 0 |
| (c) Producing regional water quality planning information. | 12 | 38 | 50 | 0 | 0 |
| (d) Assessing the environmental impact of proposed development of change. | 0 | 63 | 25 | 12 | 0 |
| (e) Verification of other irrigation return flow models. | 0 | 25 | 50 | 25 | 0 |

6. The data necessary for the conjunctive use model comes from different kinds of monitoring systems or studies all of which have varied objectives, accuracy, and time interval characteristics. In terms of the model's purpose and scope, how would you rate the consistency of the data with their use and interpretation in the following areas.

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| (a) Soil water movement | 0 | 25 | 25 | 50 | 0 |
| (b) Soil chemistry | 0 | 37 | 38 | 25 | 0 |
| (c) Groundwater movement | 0 | 12 | 38 | 38 | 0 |
| (d) Groundwater chemistry | 0 | 12 | 12 | 50 | 26 |
| (e) Surface distribution of irrigation diversions | 0 | 38 | 62 | 0 | 0 |
| (f) Consumptive use | 0 | 38 | 62 | 0 | 0 |
| (g) Reservoir operation and chemistry | 0 | 38 | 38 | 12 | 12 |

7. The flow of water, salts, and nutrients in the unsaturated soil profile has been modeled more extensively by Bureau personnel with improvements and updating of the so-called "Dutt Model." As more research is completed and better understanding of the basic principles of the unsaturated system is gained, where do you feel the most significant improvements should be made?

| | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| (a) Distribution of water under different irrigation regimes | 25 | 37 | 0 | 38 | 0 |
| (b) Nitrogen chemistry | 12 | 38 | 25 | 25 | 0 |
| (c) Fertilizer movement | 12 | 38 | 25 | 25 | 0 |
| (d) Water, salt, and nutrient root extraction patterns | 38 | 12 | 38 | 12 | |
| (e) Estimation of evapotranspiration | 25 | 25 | 38 | 12 | 0 |
| (f) Salt movement, exchange and precipitation | 0 | 63 | 37 | 0 | 0 |

8. How interested would you be in exploring the interfacing of the unsaturated chemistry model with others you may know of?

9. To what extent can you visualize this unsaturated chemistry being of use to you in your on-going or anticipated studies?

10. Bureau models of saturated flow and chemistry have been oriented primarily towards drainage design and evaluation. In those situations where a drainage system does not exist, these models impose a hypothetical system to evaluate return flow. How would you rate the model's utility to your work?

| 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|
| 50 | 0 | 38 | 12 | 0 |
| 50 | 25 | 12 | 13 | 0 |
| 12 | 38 | 38 | 12 | 0 |

11. The USBR models have been structured from subroutines which can be used as required to simulate the particular system in question. Do you feel that sufficient detail has been given for a user to determine when it is appropriate to use or not use a particular subroutine?

- No
- Yes, providing considerable study or effort is expended to get on top of actual workings of the model.
- No, however, I'm not certain that the USBR personnel should be expected to consider all potential problems. Many problems will only be obvious to those with experience in a given area.
- Yes, certainly with planned manuals.
- Yes, for some, no for others. Should have math models and method of solution. Not everyone has access to Bulletin 196 and other USBR citations.
- Yes, but it is not clear that the information is sufficient for immediate implementation. Should look at dispersion effects more explicitly; general approach should transfer to natural circulation.
- Yes
- Yes

12. The impetus in developing these models has been the need to assess the effect of irrigating large acreages on the quality of the return flow. This requires compromises in detail and assumptions regarding homogeneity of properties in soil units. What changes would you suggest to improve the models for use in modeling large areas?

- Sensitivity studies and determination of field variability.

- Movement of water and associated chemistry through aquifers or other portions of the groundwater system.

- How do we average across various soils? I'm not certain that we can just assume an average soil profile.

- In some cases, may be able to break nodes down by soils, rather than by contiguous areas.

- Groundwater and its chemistry; pickup of salts, sediments, phosphorus, etc. in return flows; consider organic N and suspended N in surface irrigation return flows; time dependent root activity and uptake; dynamic reservoir quality modeling.

- There may be a need for models covering an intermediate level of detail.

- Simplify.

13. General Comments?

- Don't feel that the USBR conjunctive use model is that good. Know of others that can produce as good or better results. Feel that concept is great, however.

## APPENDIX E

## BIBLIOGRAPHY--PLANT ROOT EXTRACTION OF WATER AND SOLUTES


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## APPENDIX G

## RESULTS OF TAKE-HOME QUESTIONNAIRE

Included below are the questions and individual responses of the ten participants who sent back their take-home questionnaire.

1. During the first session of this workshop, a list of five objectives we had hoped to accomplish were passed out and discussed. In your view, how well has this workshop met these goals?

   a. The workshop has met these goals very well. With regard to objective 4, the present and future needs did not seem to come out as explicitly as might have been hoped.

   b. The workshop met the goals fairly well.

   c. Very well!

   d. Objectives 1, 2, 3 and 5 met, objective 4 addressed only indirectly and not to sufficient breadth and scope.

   e. I believe the objectives were met, in the main. Objective 4 was not dealt with in a great deal of detail, except insofar as the discussion of a library of subroutines applied to this objective. Objective 5 may pretty well have been already met by the people attending because of their own background in modeling.

   f. I believe the general intent and goals of the IRF workshop were met, especially with regard to exposure of the USBR model and modelers. The group from outside the Bureau should be of help in exposing the USBR model to other research personnel and users.

   g. --

   h. I believe the goals as given in objectives 2 and 3 were fully accomplished. The Bureau personnel did not raise probing questions about research needs identified by others at the conference. However, they did give us a good insight into their philosophy of modeling and of verification. I may have a biased

view but I believe the degree of interdisciplinary awareness of the problems associated with irrigation return flows quality is highly developed within the Western U.S., particularly among scientists and extension personnel interested in the soil-plant-water system. Consequently, I view objectives 1, 4 and 5 more from the perspective of how well we, the participants, exchanged comments and ideas. I have the feeling we tried, but, because of the high degree of commonality among us, some comments and ideas were traded back and forth rather casually. For example, did we really attempt to prove Ken's call to simplicity?

i. 1 met partially, provided an opportunity not "the" vehicle
2 met
3 met
4 opportunity again provided
5 most present already had such an awareness

j. Has accomplished them in a very satisfactory manner. Workshop initiators can feel proud of the job they have done.

2. The workshop hopefully covered topics outside of most individual interests. To what extent do you feel the introduction to people of varied interests and work of new dimensions have expanded your own perceptions?

a. Several specific items were new to me: (a) Finite elements, (b) mass balance problems associated with saturated flow to tile drains, (c) Bresler's treatment of dispersion coefficients, and (d) the possibility of obtaining the root to 3rd and 4th order equation in closed form. Another stimulating question was how to average spatial variability in soil chemical and physical properties of soil. Also, I perceive with much greater clarity the advantage of nonsteady-state modeling in elucidating the long times associated with chemical changes in IRF!

b. I believe this is one of the principle benefits of the workshop - especially to meet with the USBR people and see how they think and how they talk about their work. Most of the rest of the group I had met before - or met people that have similar ideas.

c. I appreciated the opportunity to visit with individuals that had a different interest and philosophy in the area of soil-water and solute modeling. I picked up several good approaches to problems of interest to me and our research group. The broad dimension of interest was of value to me.

d. A great deal. I now have a better idea of the feasible approaches to problems of varying scale and required detail.

e. A great deal.

f. Generally good, but somewhat variable.

g. The workshop produced a good source of references for problems I've encountered in my limited modeling experience. It expanded considerably my perceptions of the intricacies of modeling irrigation return flow.

h. Very much, I feel my time was well spent.

i. Slightly

j. Very much. Have a much better idea of the scope of other disciplines in regards to irrigation return flow.

3. Could you comment on the time, depth, and organization of the workshop and point out where more or less emphasis should have been given?

a. Allocation of time was all right. Perhaps we could have made more concrete suggestions as to future needs and efforts. Also, maybe could have elucidated schemes and objectives for computer program library.

b. The first session on modeling philosophy should have spent more time investigating the concept of levels of model (process modeling) and the development of a subroutine library. The seven presentations in the afternoon seemed to be hurried and somewhat disorganized. I would have preferred few discussions with possibly more detail given in each session about the subject being covered. The case studies might have been better if they were included in the original discussion of the USBR models. Actual use of the models required a previous knowledge of data and format.

c. Good!

d. Practical use of modeling efforts, particularly with regards to estimates on what kinds of changes can be effected with differing management.

e. I believe the workshop was well organized and appropriately balanced. I think somewhat more time could have been spent on summarizing the state-of-the-art and assessing future needs.

f. The facilities and physical operation of the workshop were excellent. Out of personal interest, I would like to have had more discussion on the actual models being used to describe chemical processes. Also, numerical solution techniques for the various models and methods of holding computer costs to a minimum. As we go to larger, more complex problems, the cost of using the computer is going to become an important issue.

g. I believe it was about right - at least the two days that I was there. I believe the philosophical discussions the first half day were of least value.

h. Discussion of a computer library should have occurred toward the end of the workshop after we had a chance to evaluate the usefulness of models. A great opportunity to evaluate the various inputs was missed on Friday, partially because of poor attendance.

i. Organization was excellent, timing - O.K. Depth as good as expected for the time. Less emphasis on actual operation of a computer.

j. Generally and overall was very good. I personally would like to have gone into more detail on Wynn's idea of different levels of modeling efforts.

4. After having had the association of other individuals interested in irrigation return flows and hearing their comments or questions, what do you feel are the major modeling problems we must begin resolving?

a. 1) Groundwater - unsaturated flow linkage; 2) yield - management models including salt tolerance - irrigation methods interactions; and 3) methods of model verification need study. Would hydrologic and chloride balance offer a tool to simplify the process? Chloride ratios could be used to estimate mass emissions and concentration of individual ions based on soil chemistry models. There should at least be a reduction in the amount of data required without, I believe, a loss in accuracy.

b. I feel we are far from understanding the soil-water chemistry of return flow. There are many problems that come up in the field that are surprises - not according to the salinity handbook. I believe we are still far from being able to tell irrigators how to manage irrigation to minimize flows nor am I sure we could really accomplish much on a large river salt load if we could. However, the impact back on the farm may be very serious.

c. How do we handle variability as we go from small to large land areas? Also, many of our chemical models are detailed and others are rather simple in their approach; therefore, how sensitive are our models over long time periods? We need to make sensitivity analyses on these models.

d. Eliminate the inefficiency of "reinventing the wheel" as much as possible. This is a tough problem but some of the ideas concerning libraries of well documented sub-programs might go a long way.

e. Obtaining adequate data base and information on groundwater hydrology.

f. i) May need model with intermediate level of detail between the overall conjunctive use and the detailed flow and chemistry models; ii) improve calibration procedure - systematize; iii) determine real data requirements for each level; iv) use for management.

g. The proper use of a model in a particular situation. Dissemination of existing models and testing of same with written evaluations are two of the most important problems. Documentation of existing models is crucial. The process of plant-water extraction and movement of soil water are two major physical processes to be resolved.

h. Need more of a balance of treating various components or perhaps guidelines on what parts to include for a given case. It seems to me the flow under saturated conditions is crude compared to the rest of the Vol. 3 model. I think the spatial variability problem is a big one, but unlike the other factors, the theory is relatively underdeveloped.

i. Adequate data for field truth.

j. A systematic and uniform approach for integrating the modeling efforts together where this is useful. I can see a need for generalized, yet comprehensive, large-scale models with integrated subroutines that consist of more specialized models which look in more detail at specific processes.

5. What would you identify as the most important problems associated with managing and controlling irrigation return flows?

a. Defining most relevant parameters--these vary from one site to the next. Overall wish to minimize water returning by not over-irrigating and minimizing seepage losses from canals and ditches. Monitoring systems perhaps need more attention.

b. 1) Managing canal losses; 2) managing irrigation tailwater - deep percolation.

c. Sound information on applied water and ET. Realistic information on groundwater quantity and quality. Feasibility of water control on individual forms.

d. Better fix on salt pickup - salt deposition, natural sources, etc. Identification and evaluation of control technologies and their anticipated results.

e. --

f. It seems to me that the USBR model could be used to identify the major problems associated with managing and controlling irrigation return flows. This technique would also point out problems in the various submodels as well as the integration of the submodels over long periods of time.

g. Being able to predict over long periods of time what the salt buildup will be in the soil with a wide variety of management schemes.

h. Social and legal restraints and politics. In terms of irrigation management, I believe the biggest problem is in the measurement of water at the field gate and estimates of ET.

i. Splitting out the natural contribution of salts from the effects of irrigation only.

j. Control of the water throughout the irrigation system. It will take considerably more effort and definition of the interflow and groundwater portions of the system.

6. What suggestions and recommendations would you make to the Bureau of Reclamation for improving the capability of their models in light of the objectives for which they were developed and are expected to be utilized?

a. --

b. It would appear to me that the USBR effort is rather fragmented and confused - at least I don't clearly get what they are doing. They don't seem to be talking to other people as much as they could. They don't clearly come across with what or how they are doing things.

c. It was not clear to me how the submodels were called into the main program. I would like to see a modular procedure used so that submodel changes could be made with minimum disturbance to the computer program.

d. The model assumes the presence of a subsurface drainage system that is not present in many of our applications. Sub-programs capable of handling other saturated flow situations would be helpful.

e. Consider case of no underdrain. Improve interfacing between different models, i.e., conjunctive use and routing for example. Consider steady-state approach.

f. Include anisotropy in saturated flow model, allow bare soil evaporation in unsaturated flow model, clarify ACUMEN subsurface flow structure.

g. 1) More extensive field testing; 2) expand capabilities of unsaturated flow to include layered soil, hystersis, modify extraction terms.

h. Overall it is a very good effort. Probably stress two-dimensional subsurface part and put internodal transfer on a more scientific basis. Check carefully for errors arising strictly from computational part, e.g., due to inadequate time or space steps. Accept

fact that programs will continue to evolve with time. Perhaps, need more flexibility on running separate parts alone.

i. Get a more physically based model, better control on field data, more candor, and more humility in their claims.

j. More integration into a total or complete package or model rather than the 3-box separate modeling effort.

7. Would you give us your frank opinion of the workshop which previous questions did not address?

a. I, personally, gained a lot from the workshop. Realistically, the USBR models will be of the most use to the Bureau itself. I'm interested primarily in small pieces of the overall model and will profit more from the write-ups and descriptions than from the programs themselves.

b. --

c. It was worthwhile!

d. I think the workshop was very worthwhile from my personal standpoint.

e. I thought the workshop was a very worthwhile effort. The idea of a library of programs should be considered further as it would help many researchers evaluate what is available and methods of approaching their specific problem. However, the various computer libraries, such as SHARE (Triangle Universities Computation Center, Research Triangle Park, N.C.), should be considered before a lot of effort is expended.

f. Another conference should be held, but, at this one, the legal, farming, research, economic, Bureau and EPA interests should be represented to assess the social-economic implications associated with modeling efforts.

g. Although math models and solutions were described and referred to in presentations, handout materials did not contain such information for study prior to workshop. USBR made an admirable effort in meeting

their EPA project objectives, but there seems to be an imbalance between detailed chemical modeling and physical modeling. I believe some of the participants were reluctant in making constructive criticisms and/or comments. Perhaps they will feel more at ease with this take-home questionnaire. Many of the participants have not had the experience of tackling large-scale modeling.

h. The main value of any workshop is to get to exchange ideas with people. This the workshop did very well. It allowed me to get together with the USBR people and spend some time with them and really try and find out what they are doing. It also helped me to realize where the work I am doing fits in the whole scheme of things and helps to put it in perspective. It certainly demonstrated how disorganized we all are and how poor many of our models are. It also demonstrated again the great value of keeping in contact with each other. I suspect, as a result of the conference, some of us will make some changes in our research efforts.

i. I enjoyed getting acquainted with the individuals present and sharing ideas.

j. It was a first-class effort. I can think of no constructive criticism that applies to the workshop. Those topics that are pertinent were covered. Time allowed to discuss each item was appropriate and reasonable. I have to offer my congratulations on a fine job.